Enclosure

Mars Climate Orbiter Failure

The Mars Climate Orbiter (MCO) Failure Mishap Investigation Board was formally established by NASA's Associate Administrator for Space Science (OSS) on October 15, 1999.

The MCO Mission objective was to orbit Mars as the first interplanetary weather satellite and provide a communications relay for the Mars Polar Lander (MPL) which was due to reach Mars in December 1999. The MCO was launched on December 11, 1998, and was lost sometime following the spacecraft's entry into Mars occultation during the Mars Orbit Insertion (MOI) maneuver. The spacecraft's carrier signal was last seen at approximately 09:04:52 UTC on Thursday, September 23, 1999.

The Board was established to gather information, analyze, and determine the facts, as well as the actual or probable cause(s) of the MCO Mission Failure Mishap in terms of (1) dominant root cause(s), (2) contributing cause(s), and (3) significant observations and to recommend preventive measures and other appropriate actions to preclude recurrence of a similar mishap.

An immediate priority for NASA was the safe landing on Mars on December 3, 1999, of the Mars Polar Lander (MPL) spacecraft, then en route to Mars. The Board's investigation was conducted recognizing the time-criticality of the MPL landing, and the activities the MPL mission team needed to perform to successfully land the MPL spacecraft on Mars. Hence, the Board's first report was to focus on any lessons learned from the MCO mission failure in order to help assure MPL's safe landing on Mars. The Board completed its first report, which was accepted, approved and released by the Associate Administrator for Space Science and the Associate Administrator for Safety and Mission Assurance on November 10, 1999.

On January 3, 2000, the Associate Administrator for Space Science revised the objectives of the Board's second and final report to broaden the area of investigation beyond the MCO failure. The Board was to investigate a wide range of space science programs and to make recommendations regarding project management within NASA, based upon reviewing lessons learned from this broader list of programs.

The Board was also asked to address additional MCO findings and recommendations not related to MPL (and thus not reported in the first report), the ideal project management process to achieve "Mission Safety First," the current project management process and where improvements are needed, recommendations for bridging the gap between the current and ideal projects, and metrics for measuring project performance regarding mission safety. The Board completed its final report, which was accepted, approved and released by the Associate Administrator for Space Science and the Associate Administrator for Safety and Mission Assurance on March 13, 2000.

Summary of Contents and Major Recommendations/Findings Contained in the First Report of MCO Mishap Investigation Board, Released November 10, 1999

The first Board report focused on any aspects of the MCO mishap that had to be addressed in order to contribute to the Mars Polar Lander's safe landing on Mars. The Mars Polar Lander (MPL) entry-descent-landing sequence was scheduled for December 3, 1999. The Board determined that the root cause for the loss of the MCO spacecraft was the failure to use metric units in the coding of a ground software file, used in trajectory models.

During the 9-month journey from Earth to Mars, propulsion maneuvers were periodically performed to remove angular momentum buildup in the on-board reaction wheels (flywheels). These Angular Momentum Desaturation (AMD) events occurred 10-14 times more often than was expected by the operations navigation team. This was due to the fact that the MCO solar array was asymmetrical relative to the spacecraft body as compared to Mars Global Surveyor (MGS) which had symmetrical solar arrays. This asymmetric effect significantly increased the Sun-induced (solar pressure-induced) momentum buildup on the spacecraft. The increased AMD events, coupled with the fact that the angular momentum (impulse) data was in English units, rather than metric units, resulted in small errors being introduced in the trajectory estimate over the course of the 9-month journey. At the time of Mars insertion, the spacecraft trajectory was approximately 170 kilometers lower than planned. As a result, MCO either was destroyed in the atmosphere or re-entered heliocentric space after leaving Mars' atmosphere.

While mistakes occur in spacecraft projects, sufficient processes are normally in place to identify such mistakes before they become critical to mission success. Unfortunately, for MCO, the root cause was not caught by the processes in-place within the MCO project.

A summary of the contributing causes and recommendations for MPL are listed below.

Contributing Causes:

* undetected mis-modeling of spacecraft velocity changes;
* navigation team unfamiliar with spacecraft;
* trajectory correction maneuver number 5 not performed;
* system engineering process did not adequately address transition from development to operations;
* inadequate communications between project elements;
* inadequate operations navigation team staffing;
* inadequate training; and,
* verification and validation process did not adequately address ground software.

Recommendations for MPL:

* verify the consistent use of units throughout the MPL spacecraft design and operations;
* conduct software audit for specification compliance on all data transferred between JPL and Lockheed Martin Astronautics;
* verify Small Forces models used for MPL;
* compare prime MPL navigation projections with projections by alternate navigation methods;
* train Navigation Team in spacecraft design and operations;
* prepare for possibility of executing trajectory correction maneuver number 5;
* establish MPL systems organization to concentrate on trajectory correction maneuver number 5 and entry, descent, and landing operations;
* take steps to improve communications;

* augment Operations Team staff with experienced people to support entry, descent, and landing;
* train entire MPL Team and encourage use of Incident, Surprise, Anomaly process;
* develop and execute systems verification matrix for all requirements;
* conduct independent reviews on all mission critical events;
* construct a fault tree analysis for remainder of MPL mission;
* assign overall Mission Manager;
* perform thermal analysis of thrusters feedline heaters and consider use of pre-conditioning pulses; and,
* reexamine propulsion subsystem operations during entry, descent, and landing.

Summary of Contents and Major Recommendations/Findings Contained in the Report on Project Management in NASA, by the MCO Mishap Investigation Board, released March 13, 2000

Building upon the lessons learned from the MCO, and a review of 7 other failure investigation board results, the Board's Report on Project Management in NASA lays out a new vision for NASA programs and projects — to improve NASA mission success within the context of the “Faster, Better, Cheaper” paradigm. This vision, “Mission Success First,” entails a new NASA culture and new methods of managing projects.

The Board’s recommendation is that, to proceed with this culture shift, mission success must become the highest priority at all levels of the program/project and the institutional organization. The Board found that the institutional organizations were not appropriately engaged in assuring mission success. The Board recommends that all individuals should feel ownership and accountability, not only for their own work, but for the success of the entire mission. The Board asserted that, because people working on a project are the primary element of the mission-success equation, a new emphasis on people must be addressed across NASA programs.

Examining the current state of NASA’s program and project management environment, the Board found that a significant infrastructure of processes and requirements is already in place to enable robust program and project management. However, these processes have not been adequately implemented within the context of “Faster, Better, Cheaper.”

The MCO mission was conducted under NASA’s “Faster, Better, Cheaper” philosophy, developed in recent years to enhance innovation, productivity, and cost-effectiveness of America’s space program. The “Faster, Better, Cheaper” paradigm has successfully challenged project teams to infuse new technologies and processes that allow NASA to do more with less. The success of “Faster, Better, Cheaper” is tempered by the fact that some projects and programs have put too much emphasis on cost and schedule reduction (the “Faster” and “Cheaper” elements of the paradigm). At the same time, they have failed to instill sufficient rigor in risk management throughout the mission lifecycle. These actions have increased risk to an unacceptable level on these projects.

The Report summarized lessons learned from the September 1999 loss of the MCO spacecraft. The Board’s analysis of the mishap concluded that program/project breakdowns occurred in 5 key areas:

* systems engineering;
* project management;

* institutional involvement;
* communication among project elements; and,
* mission assurance.

The Report then compared these breakdowns with other failed NASA missions--as well as with a long history of successful NASA missions--and from that analysis outlined a formula for future mission success, termed “Mission Success First.” “Mission Success First” is a comprehensive project management strategy for improving the likelihood of mission success in every NASA endeavor. It addresses elements of project management that require greater attention throughout NASA:

* renewing the focus on choosing and training the right personnel;
* establishing and monitoring disciplined project processes;
* ensuring proper project execution with active participation of NASA institutional line management; and,
* aggressively developing and maintaining leading-edge technology.

Among the recommendations in the Board’s Report on Project Management in NASA are:

* improved system engineering processes;
* better, more thorough reviews;
* improved risk assessment and management;
* stronger teamwork and communications among all parties;
* improved process for reporting problems;
* operations involvement from the outset; and,
* use of a checklist formulated by the Board as a guide for project managers and review panels (see Attachment 1).

Spear Report on Improved Faster Better Cheaper Project Management

The Faster, Better, Cheaper (FBC) concept of project management was initiated by NASA in the early 1990's to challenge project managers of smaller, non-human spaceflight projects to use innovative approaches to reduce the development time of projects from 8-10 years to 3 years, and to development cost from billions to hundreds of millions. A corollary challenge was to reduce the size and complexity of spacecraft, such that singular mission failures would not significantly impact overall program objectives, if multiple smaller spacecraft were designed and built to accomplish the same mission previously accomplished by single large spacecraft. The primary Centers responsible for these types of spacecraft are the Jet Propulsion Laboratory (JPL) and NASA’s Goddard Space Flight Center.

The Mars Pathfinder was one of the first FBC projects that had extensive visibility and was a resounding success. The Project was accomplished for about $250 million, developed and launched in approximately 3 years, and successfully landed on Mars on July 4, 1997. The project was managed by JPL under the leadership of Tony Spear.

In early 1999, after the completion of several FBC projects, NASA recognized that the tools and processes for the formulation and implementation of FBC were variable between projects, and that an assessment of best practices would be useful to document and promulgate across NASA Centers. The Department of Defense had also expressed interest in FBC processes. As a result, NASA’s Chief

Engineer requested that Tony Spear assemble a team to review FBC with the objective of making recommendations on a set of principles, tools and processes for ensuring NASA's success in adopting the FBC approach to NASA project planning, management and execution. The NASA FBC Task Final Report was released on March 13, 2000.

Major recommendations of the NASA FBC Task Final Report are:

* develop and maintain "Mission Risk Signatures" with mitigation plans;
* certify FBC project teams as to experience and expertise;
* teach FBC Lessons Learned and Rules of Engagement to all Centers;
* develop a Project Performance Metric Checklist which is updated at the yearly Independent Review;
* empower an independent check of project success criteria;
* strike a better balance between challenge and risk;
* increase priority on people acquisition, motivation and training;
* assign a person at Headquarters responsible for advanced technology infusion into projects;
* strike a better balance between empowerment and assessment;
* improve teaming between NASA, industry and universities;
* increase priority of university involvement in space missions; and,
* increase use of information technology tools.

Space Shuttle Independent Assessment Report

As a result of ascent anomalies experienced on STS-93 in July 1999, NASA Associate Administrator for Space Flight, Joseph H. Rothenberg, on September 7, 1999, chartered a Space Shuttle Independent Assessment Team (SIAT) to review Space Shuttle systems and maintenance practices. The SIAT was led by Dr. Henry McDonald, Director, NASA Ames Research Center, with a team comprised of NASA, contractor, and DOD personnel.

The SIAT began work on October 4, 1999 and concluded their activities with a written report, submitted to the Associate Administrator for Space Flight on March 7, 2000.

The SIAT focused their review on 11 technical areas: avionics; human factors; hydraulics; hypergols and auxiliary power unit; problem reporting and tracking process; propulsion; risk assessment and management; safety and mission assurance; software; structures; and, wiring. The team examined NASA practices, Space Shuttle anomalies, and civilian and military aeronautical experience. NASA's goal for the SIAT study was to bring to Space Shuttle maintenance and operations processes a perspective from the best practices of the external aviation community and, where applicable or appropriate, apply these practices to the Space Shuttle. The SIAT Report was released on March 9, 2000.

The SIAT made 81 specific Recommendations in the 11 Technical Areas they reviewed; 4 recommendations were dispositioned by NASA prior to the STS-103 Hubble Servicing Mission. The SIAT summarized their recommendations in 9 issues, listed in the Executive Summary:

* NASA must support the Space Shuttle Program (SSP) with the resources and staffing necessary to prevent the erosion of flight-safety critical processes

* The past success of the Shuttle program does not preclude the existence of problems in processes and procedures that could be significantly improved.
* The SSP's risk management strategy and methods must be commensurate with the 'one strike and you are out' environment of Shuttle operations.
* SSP maintenance and operations must recognize that the Shuttle is not an 'operational' vehicle in the usual meaning of the term.
* The SSP should adhere to a 'fly what you test / test what you fly' methodology.
* The SSP should systematically evaluate and eliminate all potential human single point failures.
* The SSP should work to minimize the turbulence in the work environment and its effects on the workforce.
* The size and complexity of the Shuttle system and of the NASA/contractor relationships place extreme importance on understanding, communication, and information handling.
* Due to the limitations in time and resources, the SIAT could not investigate some Shuttle systems and/or processes in depth. An independent group may be required to9 examine these other areas and should be tasked with reviewing the Shuttle program's disposition of SIAT findings and recommendations.

The SIAT divided the remaining 77 recommendations into the following categories:

* 37 recommendations identified as "Short-Term" (solutions required prior to making more than 4 more Shuttle flights);
* 30 recommendations identified as "Intermediate" (solutions required prior to January 1, 2001); and,
* 10 recommendations identified as "Long'Term" (solutions required prior to January 1, 2005).

NASA's Johnson Space Center, the Lead Center for Human Space Flight and the Space Shuttle Program, is reviewing and evaluating the SIAT recommendations, and will formulate a plan or response, as appropriate, for each over the next several weeks.

NASA's goal for the SIAT review, as with previous independent assessments of the Space Shuttle, has been to identify opportunities to improve safety. It should be noted that the SIAT Report fully endorsed the continuation of Space Shuttle flights after disposition of the Team's immediate recommendations. The SIAT documented many positive elements during the course of their interviews with the Space Shuttle NASA/contractor workforce. Particularly noteworthy were the observations dealing with the skill, dedication, commitment and concern for astronaut safety and the entire Space Shuttle workforce. The SIAT report will provide additional input to the full range of activities already underway associated with Space Shuttle safety investments, including upgrades, maintainability, processes for shuttle safety, and quality control.

Space Shuttle Workforce

As NASA continues to assemble the International Space Station and support the infrastructure and upgrades to the Space Shuttle program as well as Expendable Launch Vehicle (ELV) commitments over the next 5 years, the workload will increase steadily. Internal and external workforce assessments have convinced NASA management that NASA Human Space Flight (HSF) civil service FTE targets must be adjusted. From internal reviews, such as NASA's Core Capabilities Study, to external evaluations by the Aerospace Safety Advisory Panel (ASAP) and the Space Shuttle Independent Assessment (SIAT), it has become apparent that the HSF workforce required immediate revitalization. Five years of buyouts and downsizing have led to serious skill imbalances and an overtaxed core workforce. As more employees have departed, the workload and stress remaining have increased, with a corresponding increase in the potential for impacts to operational capacity and safety. HSF Centers will begin to accelerate hiring in FY 2000, in order to address immediate critical skill shortfalls. After the initial hiring of 500 new personnel across the 4 HSF Centers in FY 2000, HSF workforce trends will begin a one-for-one replacement process and will allow HSF Centers to attain a steady state in civil service employment by FY 2001. NASA will continue to monitor HSF Center hires and attrition, ensuring that workforce skill balances are achieved and maintained.

NASA will work with the Office of Management and Budget, in the coming months, to conduct a personnel review with an eye toward the future. This review will assess management tools and innovative approaches for personnel management that might best equip NASA to evolve and adapt our civil service workforce in the future. This will be particularly important as NASA continues our transition from operations to a focus on advancing the frontier with cutting edge research and development in science and technology.

ISS Cost Status

Last year, NASA testified before the Congress that the FY 2000 budget would provide stability throughout the assembly of the ISS, allowing us to uphold our commitment to our International Partners on the ISS program, while providing critical contingency capabilities. This has indeed been the case. Compared to the FY 2000 budget, the FY 2001 budget request reflects an overall reduction in the budget and runout estimates through FY 2005 of about $1.2 billion. Roughly $0.8 billion of this reduction is due to the movement of funding for the Phase 2 production of the ISS Crew Return Vehicle (CRV) to the Science, Aeronautics and Technology budget account. The FY 2002-2005 funding estimates for the CRV will reside in that account pending a decision in the next 2 years on whether to proceed with an X-38-based CRV design. This decision will be made in the context of broader decisions that NASA and the Administration will make regarding future space transportation architectures. There was also an approximate $0.4 billion reduction in other ISS funding, over 5 years, to fund Agency needs and other high priority activities such as the Bioastronautics initiative.

While the 5-year funding profile for ISS has decreased in the FY 2001 budget, overall development costs are projected to increase. This growth, as in past years, is driven primarily by projected delays in reaching Development Complete. Development Complete is the point at which the ISS crew complement can be increased from 3 to 6 crew. Our current estimate is that the Development Complete schedule milestone will occur between Fall 2004-Fall 2005, with the projected cost in the range of $23–25 billion. Our estimate is that Assembly Complete schedule milestone will occur between May 2005-November 2006, with the projected cost in the range of $24-26 billion. These estimates do not reflect the full cost of contingency reserve for additional development effort and Shuttle costs that would be required to accommodate a partner or partners having difficulty meeting ISS commitments.

NASA has kept the Committee briefed on the challenges facing NASA and our International Partners on the ISS program. Both U.S. and Russian difficulties contributed to last year's schedule delay. The Russian delays were caused by a Proton launch failure investigation. The planned July 2000 launch of the Service Module is now about a year later than projected in March 1999. While there has been much discussion about the state of readiness about our Russian partner, NASA has also experienced schedule delays. U.S. launch schedules supporting the ISS have slipped as a result of the wiring safety stand-down of the Shuttle fleet. Development and testing of U.S. elements has proceeded somewhat more slowly than expected. However, the current Service Module launch schedule date provides several months of schedule margin for U.S. assembly flights.

At about this time last year, our Prime contractor reassessed their estimated level of overrun at completion of the ISS development contract. At the time, they had completed about 80 percent of the developmental effort, and their estimate of a $986 million overrun represented about 11 percent growth. Due to the level of increase in their estimate, and the fact that the development program was coming to closure, NASA initiated several additional independent analyses to establish confidence in the new Boeing estimate and to reassess Boeing's performance management processes. One of these steps was to request the NASA Inspector General (IG) to provide their assessment of the performance management and Prime costs. The IG report highlighted that Boeing continued to make optimistic estimates of their overrun. NASA continues to budget to a level higher than the Boeing estimate. The prime contract will continue to make hardware deliveries this year, as the cost to go on the development contract decreases significantly.

Gravity Probe B

Gravity Probe B is the relativity gyroscope experiment being developed by NASA and Stanford University to test two extraordinary, unverified predictions of Albert Einstein's general theory of relativity. The experiment is intended to measure, very precisely, tiny changes in the direction of spin of 4 gyroscopes contained in a satellite orbiting at a 400-mile altitude directly over the poles. The gyroscopes are designed to be so free from disturbance that they will provide an almost-perfect space-time reference system. They will measure how space and time are warped by the presence of the Earth, and, more profoundly, how the Earth's rotation drags space-time around with it. These effects, though small for the Earth, have far-reaching implications for the nature of matter and the structure of the Universe. Since the initiation of Gravity Probe B in 1988, $453 million has been spent on GP-B development.

Although the completion of the GP-B program has been a schedule and cost struggle for some time, Stanford University has made significant progress in building over 85% of the complex subsystems of GP-B. These subsystems are meeting or exceeding specifications required to conduct a creditable experiment to verify Einstein's General Theory of Relativity. Stanford has considerable technical capabilities and a high degree of dedication.

As a result of a recent functional test of GP-B's Integrated Dewar & Probe, significant technical anomalies have surfaced, which required the de-integration of the payload as well as the implementation of design modifications. A re-integration and repeat of the functional testing to verify the effectiveness of the modification and to certify the flight worthiness of the payload will follow this activity. The complex nature of this integration process, which is unlike any payload ever built, coupled with the data readout sensitivity and precision requirements of the hardware, has resulted in a substantial schedule slip as well as the cost to complete the program.

With the focus to resolve the current technical issues, NASA is aware that new issues could surface as a result of the changes being made. We are taking a number of steps to ensure that our design modification are sound and that all possible steps are taken to minimize future technical issues:

* NASA has recently intensified the direct involvement of our existing External Independent Readiness Review (EIRR) team by asking them to work closely with Stanford and the Marshall Space Flight Center (MSFC) to review all aspects of the program. This includes the proposed design modifications and daily feedback to the Stanford/MSFC design team on recommendations that promote schedule and cost control with the emphasis on mission success. The EIRR reports the status of the program regularly to NASA's Associate Administrator for Space Science.

* NASA established an Independent Review Team comprised of nationally recognized industry and Government experts in building complex space systems. This team was chartered to "conduct an assessment of the programmatic health (technical, schedule, management) of the Gravity Probe-B program" and provide immediate feedback to Stanford University, MSFC and NASA Headquarters on any modification to the design or flight qualification of the payload necessary to ensure mission success. The Independent Review Team completed its review and reported back to the Associate Administrator for Space Science in late February with the following conclusions:

Schedule Risk Assessment:

* poor prediction of progress on critical path;
* high probability that electronic boxes (already more than a year behind schedule) will impact critical path during environmental testing;
* probe repair is on critical path; and,
* additional funding needed to mitigate schedule.

Cost Risk Assessment:

* any schedule or technical issue could become a cost risk if not resolved quickly;
* need to install NASA management at Stanford for quick decision making and to insulate Stanford from outside distractions;
* refurbish Probe B as flight backup unit to mitigate potential payload recycle; and,
* technical Risk Assessment:
* Probe C neck temperature anomaly of most concern; root cause remains unknown.

As a consequence of the testing problems, GP-B has been delayed at least 18 months and is currently under consideration for an April 2002 launch. NASA's estimated cost to address the technical problems and the schedule delays is $65-100 million. As the Committee is aware, approximately $20 million of this increase has already been accommodated in NASA's FY 1999 and FY 2000 Operating Plans and in the FY 2001 budget request. Analysis is underway to define impacts to the Space Science budget to fund the remainder. A Headquarters-controlled critical milestone schedule is also in development.

During the late July timeframe, NASA expects to make a decision with respect to the future of the Gravity Probe B Program, based upon the extent to which progress is being made toward resolving the technical and schedule issues, and the extent to which remaining budget requirements will impact other Agency science priorities.

X-33 Status

The X-33 objective is to demonstrate technologies and operations concepts with the goal of reducing space transportation costs to one tenth of their current level. NASA is utilizing an innovative management strategy for the X-33 program, based on industry-led cooperative agreements, allowing a much leaner management structure, lower program overhead costs, and increased management efficiency. The X-33 program Phase II selection was made in July 1996 based on specific programmatic, business planning, and technical criteria. NASA selected the Lockheed Martin Skunk Works to lead an industry team to develop and flight test the X-33.

The X-33 is an integrated technology effort to flight demonstrate key Single Stage To Orbit (SSTO) technologies, and deliver advancements in:

* ground and flight operations techniques that will substantially reduce operations costs for a Reusable Launch Vehicle (RLV);
* lighter, reusable cryogenic tanks;
* lightweight, low-cost composite structures;

* advanced Thermal Protection Systems to reduce maintenance;
* propulsion and vehicle integration; and,
* application of New Millennium microelectronics for vastly improved reliability and vehicle health management.

The X-33 Program deals with cutting-edge technologies, such as large composite tanks, a metallic thermal protection system, innovative aerospike engines, and a lifting body approach to a launch system. The program has made considerable progress in the last year. The X-33 launch complex was completed and site activation begun. In addition, the structural testing of the liquid oxygen tank was successfully completed; the flight software was delivered and verification and validation was undertaken; the linear aerospike engine was delivered to Stennis and testing begun; the metallic TPS was flight qualified; and the liquid hydrogen composite tank was delivered to MSFC for testing. Three cryogenic and structural load tests of the hydrogen tank, based upon 105 percent of maximum flight conditions, were completed. However, after the completion of the third test, a partial failure of the outer skin of one of the 4 lobes of the tank was observed.

A failure investigation of the hydrogen tank, by a team of NASA and industry personnel, was initiated in November 1999. The failure investigation team will make a report on the root cause of the failure. Their report is expected to be released within the coming weeks. After reviewing the team's findings, NASA and the contractor will jointly agree on the approach necessary to recover from the hydrogen tank failure and then proceed with development of a recovery plan and schedule.

In an effort as technologically challenging as the X-33 program, incidents like the tank failure—while disappointing — are not unexpected. Furthermore, it is important to remember that, thanks largely to our commitment to safety and the various independent reviews we have carried out, the tank failure occurred in the test stand rather than in flight.

As the X-33 program has evolved, our industry partners have been exceptional in accommodating such challenges. While industry's investment has grown significantly since the beginning of the program, NASA's financial investment in the X-33 has not increased. We have, however, utilized additional staff across the Centers to help resolve issues as they have arisen. As other challenges develop in the future, we will assist our industry partners to the extent that our program priorities permit.